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RESEARCH MEMORANDUM

LONGITUDINAL CHARACTERISTICS OF TWO 47.7° SWEPTBACK WINGS WITH ASPECT RATIOS OF 5.1 AND 6.0 AT REYNOLDS NUMBERS UP TO 10 × 10^6

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NATIONAL ADVISORY COMMITTEE
FOR AERONAUTICS

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SUMMARY

A low-speed investigation of the longitudinal aerodynamic characteristics of a 47.7° sweptback wing was conducted in the Langley 19-foot pressure tunnel in order to provide large-scale data on relatively high-aspect-ratio sweptback wings. The wing featured interchangeable wing tips which provided aspect ratios of 5.1 and 6.0 with corresponding taper ratios of 0.383 and 0.313. NACA 64-210 airfoil sections were employed normal to the 0.286 chord line. The data were obtained through a range of Reynolds numbers varying from approximately 1.1×10^6 to 10.0×10^6 and Mach numbers of 0.06 to 0.25.

The maximum lift coefficient increased slightly as the Reynolds number was increased from 2.0×10^6 to 8.0×10^6, where maximum values of 1.19 and 1.20 were obtained for the aspect ratio 5.1 and 6.0 wings, respectively. Increasing the Reynolds number to 10.0×10^6 caused a decrease in maximum lift which was attributed to compressibility effects. The aerodynamic centers of both wings remained at an essentially constant position up to moderate lift coefficients. Leading-edge separation near the tips then caused an abrupt unstable moment break. The lift coefficient at which the abrupt pitching-moment break occurred increased between Reynolds numbers of about 2.0×10^6 and 4.5×10^6, and maximum values of approximately 0.86 and 0.82 were obtained for the aspect ratio 5.1 and 6.0 wings, respectively. Although a vortex type of flow was shown to exist at all test values of the Reynolds number, a stabilizing effect of the vortex flow was evident only at the lowest test Reynolds number. The maximum lift-drag ratios were obtained at a lift coefficient of about 0.25 and were approximately 25.6 and 27.8 for the aspect ratio 5.1 and 6.0 wings, respectively.

INTRODUCTION

An investigation is being conducted on a 47.7° sweptback wing with aspect ratios 5.1 and 6.0 to provide low-speed large-scale data on relatively high-aspect-ratio sweptback wings. In order to indicate the effect of a small change in aspect ratio on the stability characteristics, the aspect ratio 6.0 wing was reduced to an aspect ratio of 5.1 by means of interchangeable wing tips.

The present paper contains the longitudinal aerodynamic characteristics and the lift-drag ratios obtained on the plain wings. The data were obtained through a Reynolds number range from about 1.1×10^6 to 10.0×10^6.

SYMBOLS

C_L	lift coefficient (Lift/qS)
$C_{L(inflection)}$	lift coefficient at which abrupt pitching-moment change is observed
$C_{L_{max}}$	maximum lift coefficient
C_D	drag coefficient (Drag/qS)
C_m	pitching-moment coefficient referred to $0.25\bar{c}$ (Pitching moment/$qS\bar{c}$)
q	dynamic pressure ($\rho V^2/2$)
S	wing area
V	velocity
ρ	mass density of air
$\bar{c}$	mean aerodynamic chord
A	aspect ratio (b^2/S)
b	wing span

R	Reynolds number ($\rho V \bar{c}/\mu$)
M	Mach number (V/a)
μ	coefficient of viscosity
a	speed of sound
L/D	lift-drag ratio
α	angle of attack

MODEL

The wing had a leading-edge sweep angle of 47.7° and interchangeable wing tips which gave aspect ratios of 5.1 and 6.0. The aspect ratio 5.1 and 6.0 wings had corresponding taper ratios of 0.383 and 0.313, respectively. Uniform twist about the 0.286 chord line produced 1.32° and 1.72° of washout for the aspect ratio 5.1 and 6.0 wings, respectively. In both cases the dihedral angle was zero. The geometry and dimensions of the two wing plan forms are presented in figure 1. Standard roughness, as described in reference 1, was applied along the entire span of the aspect ratio 5.1 wing for the roughness tests. The model mounted in the Langley 19-foot pressure tunnel is shown in figure 2.

TESTS

The majority of tests were made at a tunnel pressure of 33 pounds per square inch. A few runs were made at atmospheric pressure for the two wing configurations for the purpose of obtaining data at a lower Reynolds number. The lift, drag, and pitching moment were measured through an angle-of-attack range from -2° through the maximum lift. The variation of the test Mach number with Reynolds number is shown in figure 3.

The effect of leading-edge roughness on the aerodynamic characteristics was investigated for the aspect ratio 5.1 wing at Reynolds numbers of 3.0×10^6 and 6.0×10^6. Visual observations of the flow patterns were made by means of tufts attached to the upper surface of the wing. The tuft studies were made at Reynolds numbers of about 2.0×10^6 (aspect ratio 5.1) and approximately 6.0×10^6 (aspect ratios 5.1 and 6.0).

CORRECTIONS TO DATA

The lift, drag, and pitching-moment coefficients have been corrected for support strut interference and air-stream misalinement effects.

The jet-boundary corrections to the angle of attack and drag coefficient were based on the method of reference 2 and are as follows:

	A = 5.1	A = 6.0
$\Delta\alpha$	$0.905C_L$	$0.980C_L$
ΔC_D	$.0139{C_L}^2$	$.0152{C_L}^2$

Corrections to the pitching moment due to tunnel-induced distortion of the span loading were made as follows:

	A = 5.1	A = 6.0
ΔC_m	$0.004C_L$	$0.008C_L$

Corrections were also made for wake blockage effects. All corrections were added to the data.

RESULTS AND DISCUSSION

Pitching-Moment Characteristics

From the analysis presented in reference 3, a wing of 47.7° sweepback and an aspect ratio of either 5.1 or 6.0 may be expected to exhibit instability in the high-lift-coefficient range. Figures 4 and 5 show that the expected instability occurred for both the aspect ratio 5.1 and 6.0 wings at moderate lift coefficients.

The abrupt unstable moment break can be attributed to separation near the tips. Figure 6 indicates the presence of spanwise cross flow prior to the initial separation. As the angle of attack was increased, the separation spread inboard and the pitching moment remained unstable until a point was reached where the inboard sections began to lose lift; and, as shown by the plots of pitching moment against angle of attack (figs. 4 and 5), the slope of the moment curve became negative, thus indicating stability at the maximum lift. Some of the curves of pitching moment against angle of attack for the high Reynolds numbers were not obtained because the forces exceeded the limits of the balance system.

From the lift-drag polars of figures 4 and 5, it can be seen that a rapid increase in the drag coefficient coincided with the lift coefficient at which the instability occurred.

As shown in figures 4 and 5, the pitching-moment curves were linear in the range of lift coefficients below the inflection point in the range of Reynolds numbers from 2.0×10^6 to 10.1×10^6. The calculated location of the aerodynamic center, determined by the method of reference 4, was in good agreement with the measured values in the low lift range. The following table compares the measured and calculated locations of the aerodynamic center in percent mean aerodynamic chord:

A	Calculated	Experimental	
		$R \approx 2.0 \times 10^6$	$R \approx 6.0 \times 10^6$
5.1	30.3	30.8	32.5
6.0	34.7	34.8	37.5

It is interesting to note that the pitching-moment curve obtained at a Reynolds number of about 1.10×10^6 exhibited an increase in stability prior to the unstable break. In references 5 and 6 similar moment curves for sweptback wings were obtained, and the increase in stability was attributed to the effects of vortex flow on the upper surface of the wings.

A survey of the air flow over the present wing was made at a Reynolds number of about 1.10×10^6 using a slender probe with a single wool tuft. The survey showed that a vortex flow developed at an angle of attack which corresponded to the angle of attack at which the increase in stability occurred. The vortex appeared to originate at the apex of the wing, sweep back at an angle slightly greater than the leading-edge sweep angle, and finally turn back into the stream direction near the tip. As the angle of attack was increased, the point at which the vortex turned back toward the stream direction shifted inboard and the portion of the tip outboard of the vortex was observed to be stalled.

The pitching-moment curves of figure 4(b) do not exhibit the increase in stability at Reynolds numbers in excess of 1.10×10^6. Probe surveys made at a Reynolds number of about 3.98×10^6 revealed that the development of the vortex flow was delayed to a much greater angle of attack than at the lower Reynolds number. The delay in the development of the vortex flow due to increasing Reynolds number was also observed in references 5 and 6. It was observed that as the angle of attack was increased the tip stalling occurred before the vortex flow became evident. The survey also indicated that when the vortex flow developed at the higher Reynolds number, it turned into the stream direction at a wing station considerably inboard of the tips.

It should be noted that an inboard location of the vortex flow may contribute to the instability in the high angle-of-attack range.

Lift Characteristics

Maximum lift coefficients of 1.19 and 1.20 were obtained at a Reynolds number of about 8.0×10^6 for the aspect ratio 5.1 and 6.0 wings, respectively. Figure 7 shows that the maximum lift coefficients increased slightly with increasing Reynolds number in the range of Reynolds numbers from about 2.0×10^6 to 8.0×10^6. A decrease in $C_{L_{max}}$ occurred when the Reynolds number was increased to about 10.0×10^6. The decrease in $C_{L_{max}}$ may be attributed to the effects of compressibility such as described in reference 7.

Figure 7 shows that a large increase in the inflection lift coefficient occurred when the Reynolds number was increased from about 2.0×10^6 to 4.5×10^6. The separation near the tips may have been delayed to higher angles of attack by a reduction in the spanwise cross flow, as indicated in figure 6, in addition to a normal scale effect on the angle of stall.

The lift-curve slopes at low angles of attack were 0.061 and 0.062 for the aspect ratio 5.1 and 6.0 wings, respectively. Calculated values of the lift-curve slope based on the Weissinger method (reference 4) were 0.057 and 0.059 for the aspect ratio 5.1 and 6.0 wings, respectively.

Lift-Drag Ratio

The variation of the lift-drag ratios with lift coefficient is presented in figure 8. The maximum values of L/D were obtained at a lift coefficient of about 0.25 and were approximately 25.6 and 27.8 for the aspect ratio 5.1 and 6.0 wings, respectively. The relative increase in L/D for the aspect ratio 6 wing became smaller as the lift coefficient was increased above 0.25 and became zero at a lift coefficient of about 0.8.

Effects of Roughness

The effects of leading-edge roughness on the aerodynamic characteristics of the aspect ratio 5.1 wing are shown in figure 9. Roughness decreased the maximum lift coefficient about 0.06 at a Reynolds number of 6.0×10^6 and approximately 0.03 at a Reynolds number of 3.0×10^6. The lift-curve slopes were unaffected by roughness.

Figure 9(b) shows that the roughness caused a considerable reduction in the inflection lift coefficient at a Reynolds number of about 6.0×10^6 but had a negligible effect at a Reynolds number of 3.0×10^6. The effect of the roughness is similar to the effect of a low Reynolds number in that the energy of the turbulent boundary layer is reduced and separation may occur at a lower angle of attack.

At a Reynolds number of 6.0×10^6, the pitching-moment curves were linear up to the inflection lift coefficient for both the smooth and rough configurations. The aerodynamic center shifted forward about 2.3 percent mean aerodynamic chord, however, when the roughness was added. A forward movement of the aerodynamic center due to roughness was also apparent at the lower Reynolds number in that the slope of the moment curve gradually decreased.

From figure 9 it can be seen that the effects of roughness on the drag rise correspond with the effects on the unstable moment break. The drag rise occurred at a much lower lift coefficient for the rough condition at a Reynolds number of 6.0×10^6 but was little affected at a Reynolds number of 3.0×10^6.

SUMMARY OF RESULTS

The results of an investigation of a 47.7° sweptback wing, for which aspect ratios of 5.1 and 6.0 were obtained by means of interchangeable tips, are summarized as follows:

1. Maximum lift coefficients of 1.19 and 1.20 were obtained for the aspect ratio 5.1 and 6.0 wings, respectively. The maximum lift

coefficients increased slightly between Reynolds numbers of 2.0×10^6 and 8.0×10^6 and decreased between Reynolds numbers of 8.0×10^6 and 10.0×10^6.

2. The aerodynamic centers of both wings remained at an essentially constant position up to moderate lift coefficients. Leading-edge separation near the tips then caused an abrupt unstable moment break. A large increase in the inflection lift coefficient (lift coefficient at which abrupt pitching-moment break occurs) occurred between Reynolds numbers of about 2.0×10^6 and 4.5×10^6. Maximum values of the inflection lift coefficients for the aspect ratio 5.1 and 6.0 wings were approximately 0.86 and 0.82, respectively.

3. A vortex flow was shown to exist on the wing. The vortex flow affected the pitching-moment characteristics at a Reynolds number of about 1.10×10^6 but its effects were minimized by tip stall at the higher Reynolds numbers.

4. The maximum lift-drag ratios were obtained at a lift coefficient of about 0.25 and were approximately 25.6 and 27.8 for the aspect ratio 5.1 and 6.0 wings, respectively.

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REFERENCES

1. Abbott, Ira H., Von Doenhoff, Albert E., and Stivers, Louis S., Jr.: Summary of Airfoil Data. NACA Rep. 824, 1945.

2. Eisenstadt, Bertram J.: Boundary-Induced Upwash for Yawed and Swept-Back Wings in Closed Circular Wind Tunnels. NACA TN 1265, 1947.

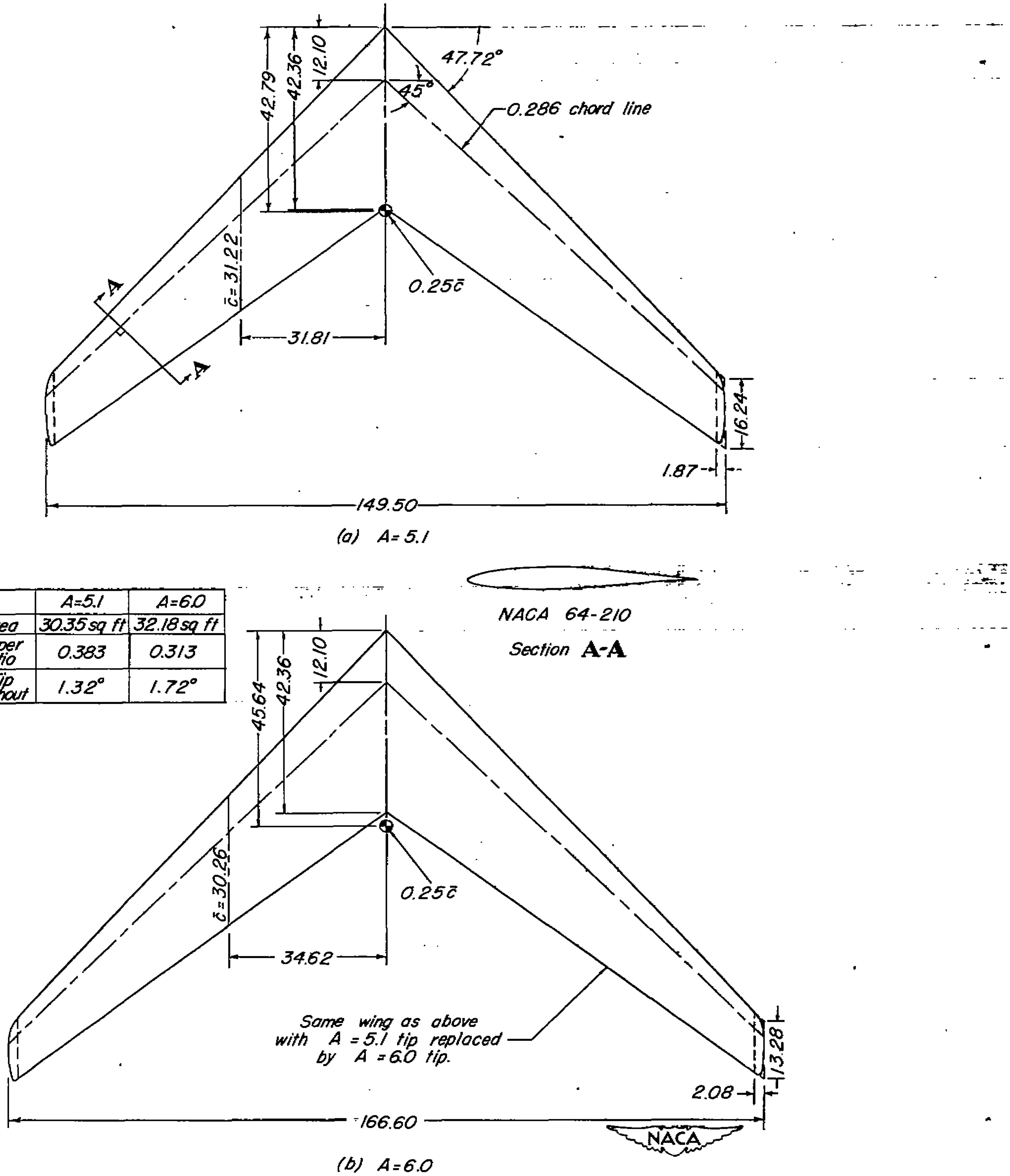
3. Shortal, Joseph A., and Maggin, Bernard: Effect of Sweepback and Aspect Ratio on Longitudinal Stability Characteristics of Wings at Low Speeds. NACA TN 1093, 1946.

4. DeYoung, John: Theoretical Additional Span Loading Characteristics of Wings with Arbitrary Sweep, Aspect Ratio, and Taper Ratio. NACA TN 1491, 1947.

5. Fitzpatrick, James E., and Foster, Gerald V.: Static Longitudinal Aerodynamic Characteristics of a 52° Swept-Back Wing of Aspect Ratio 2.88 at Reynolds Numbers from 2,000,000 to 11,000,000. NACA RM L8H25, 1948.

6. Cahill, Jones F., and Gottlieb, Stanley M.: Low-Speed Aerodynamic Characteristics of a Series of Swept Wings Having NACA 65A006 Airfoil Sections. NACA RM L9J20, 1950.

7. Furlong, G. Chester, and Fitzpatrick, James E.: Effects of Mach Number and Reynolds Number on the Maximum Lift Coefficient of a Wing of NACA 230-Series Airfoil Sections. NACA TN 1299, 1947.



	A=5.1	A=6.0
Area	30.35 sq ft	32.18 sq ft
Taper ratio	0.383	0.313
Tip washout	1.32°	1.72°

Figure 1.- Geometry of the 47.7° sweptback wings with aspect ratios of 5.1 and 6.0.

[redacted]

Figure 2.- The 47.7° sweptback wing of aspect ratio 5.1 mounted in the Langley 19-foot pressure tunnel.

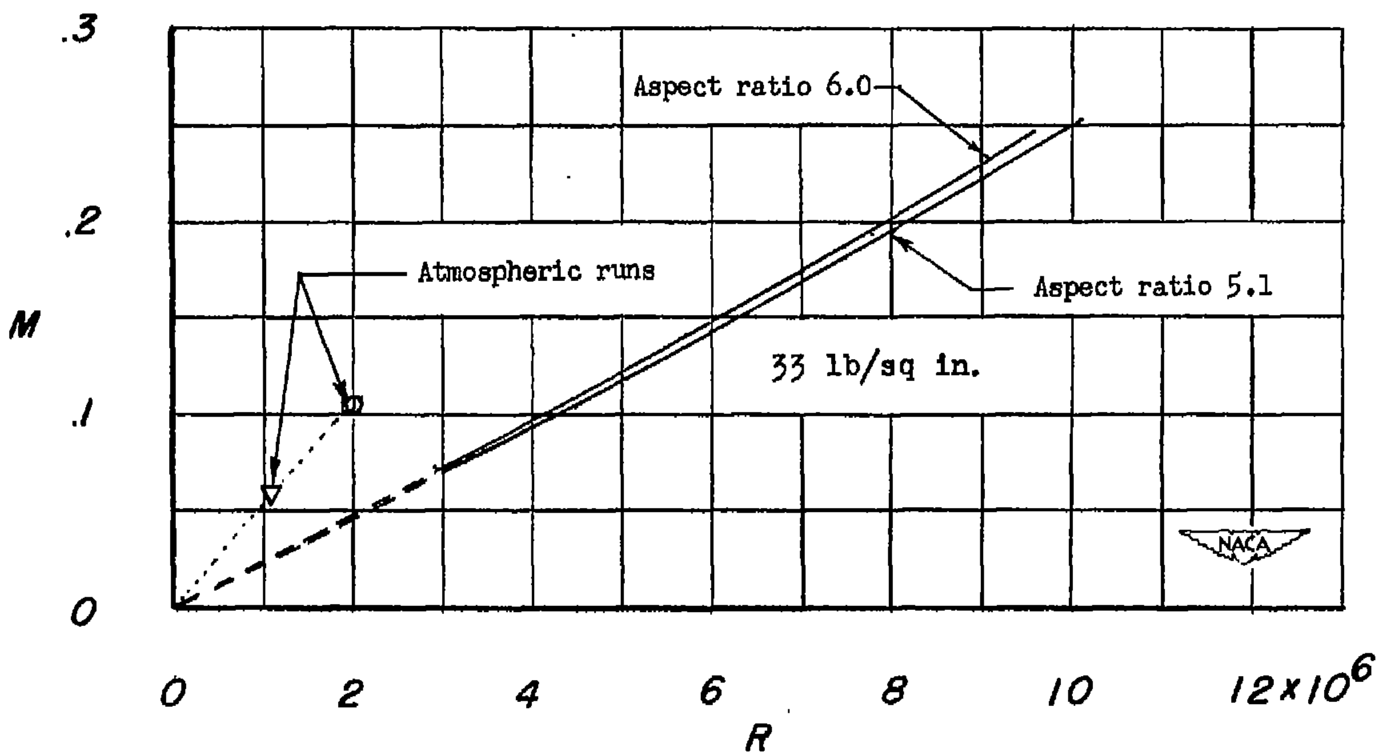
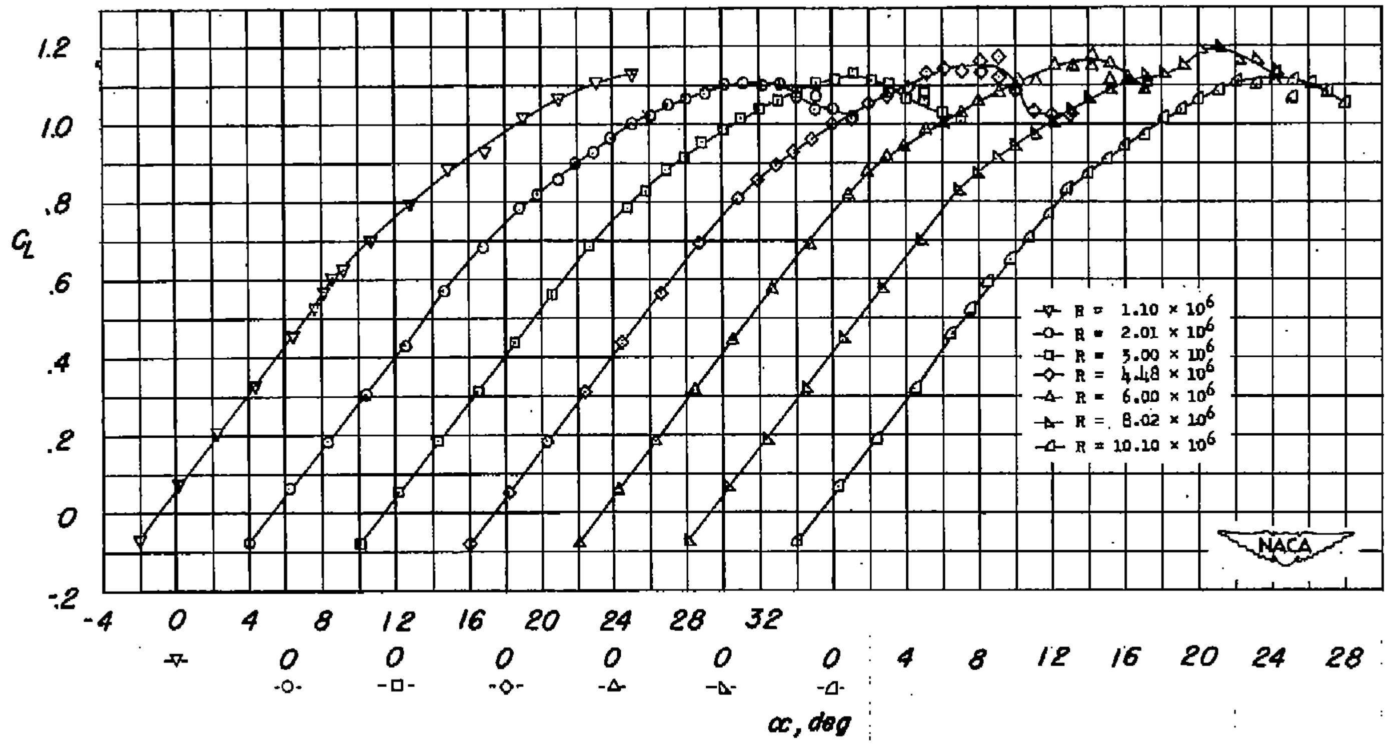
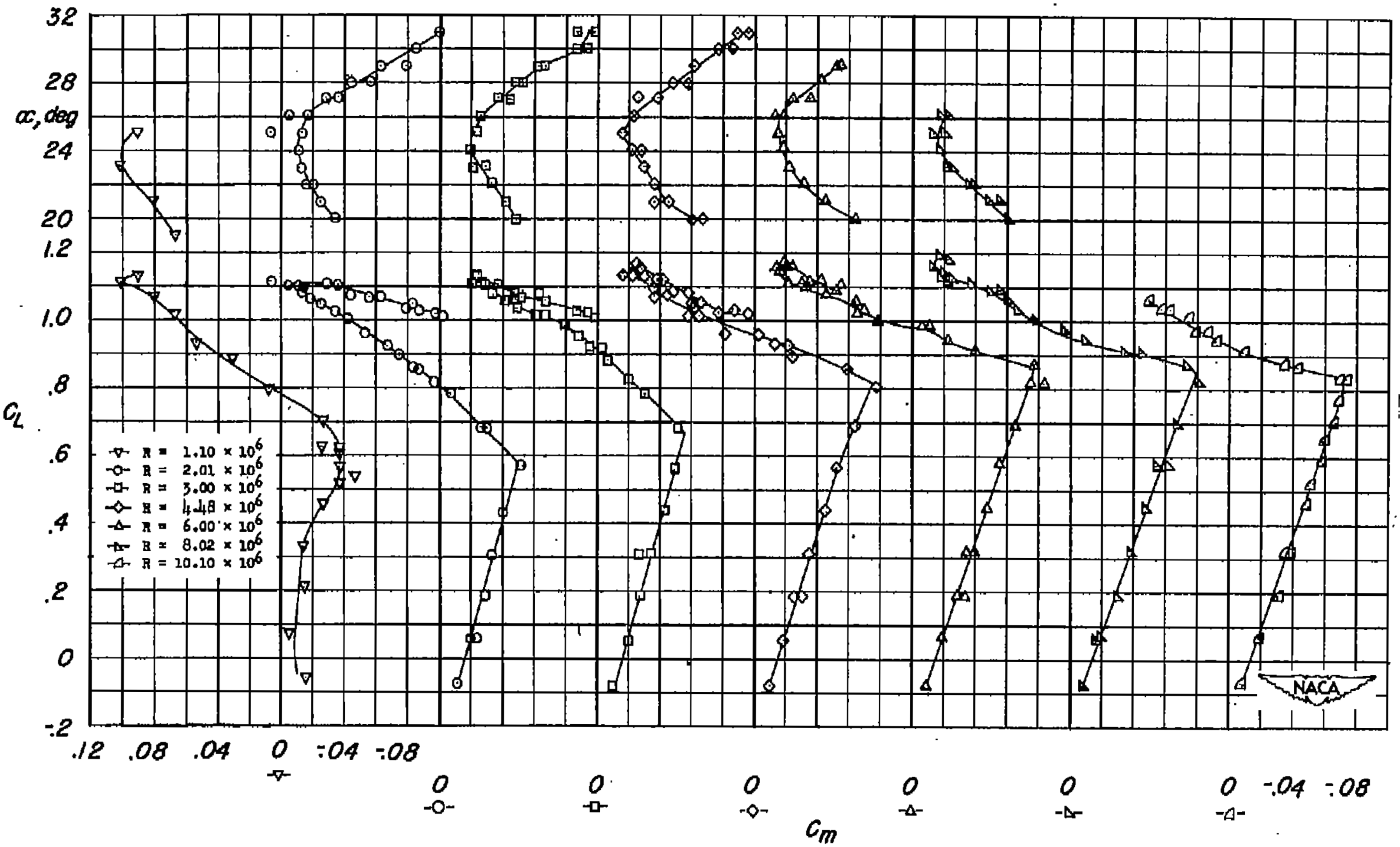


Figure 3.- Variation of Mach number with Reynolds number for the wings of 47.7° sweepback and aspect ratios of 5.1 and 6.0.



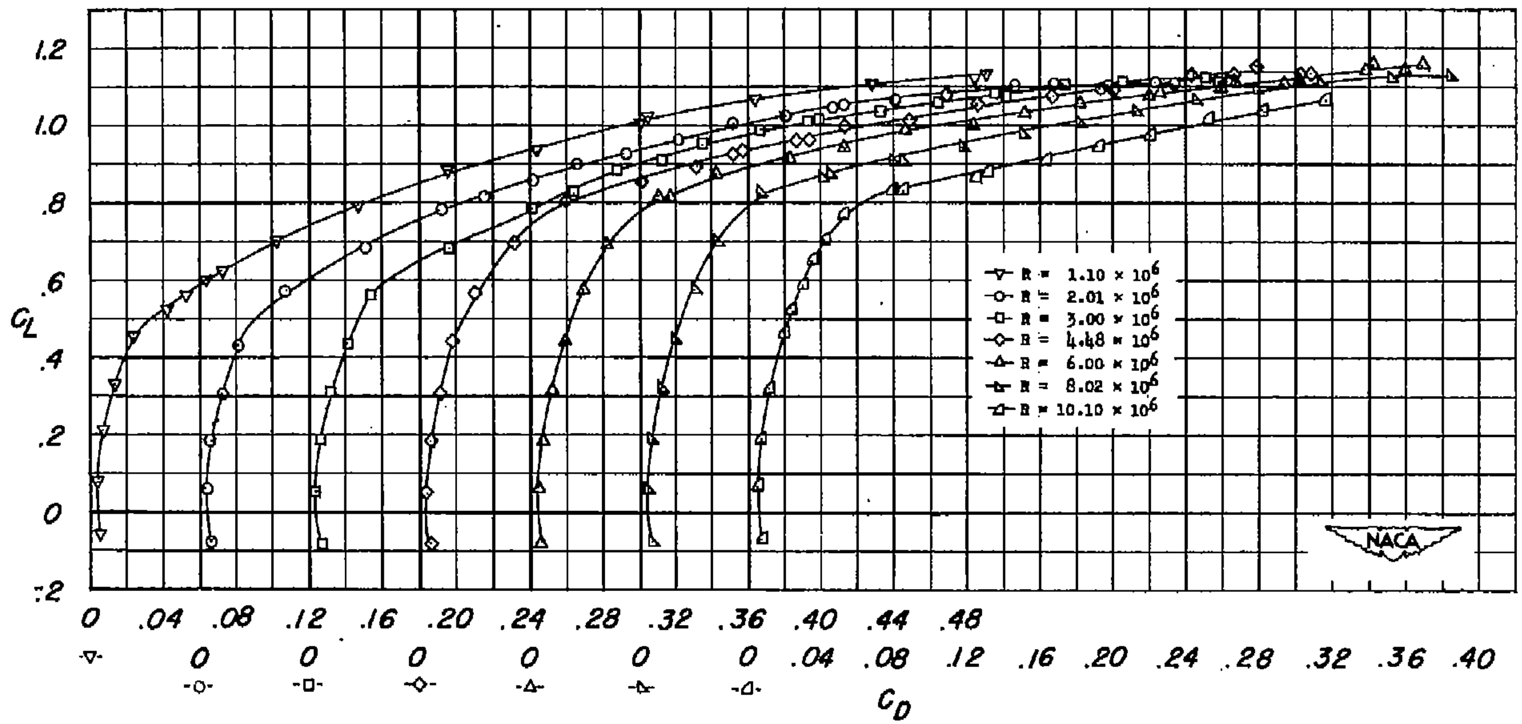
(a) C_L plotted against α.

Figure 4.- Effects of Reynolds number on the aerodynamic characteristics of a 47.7° sweptback wing of aspect ratio 5.1.



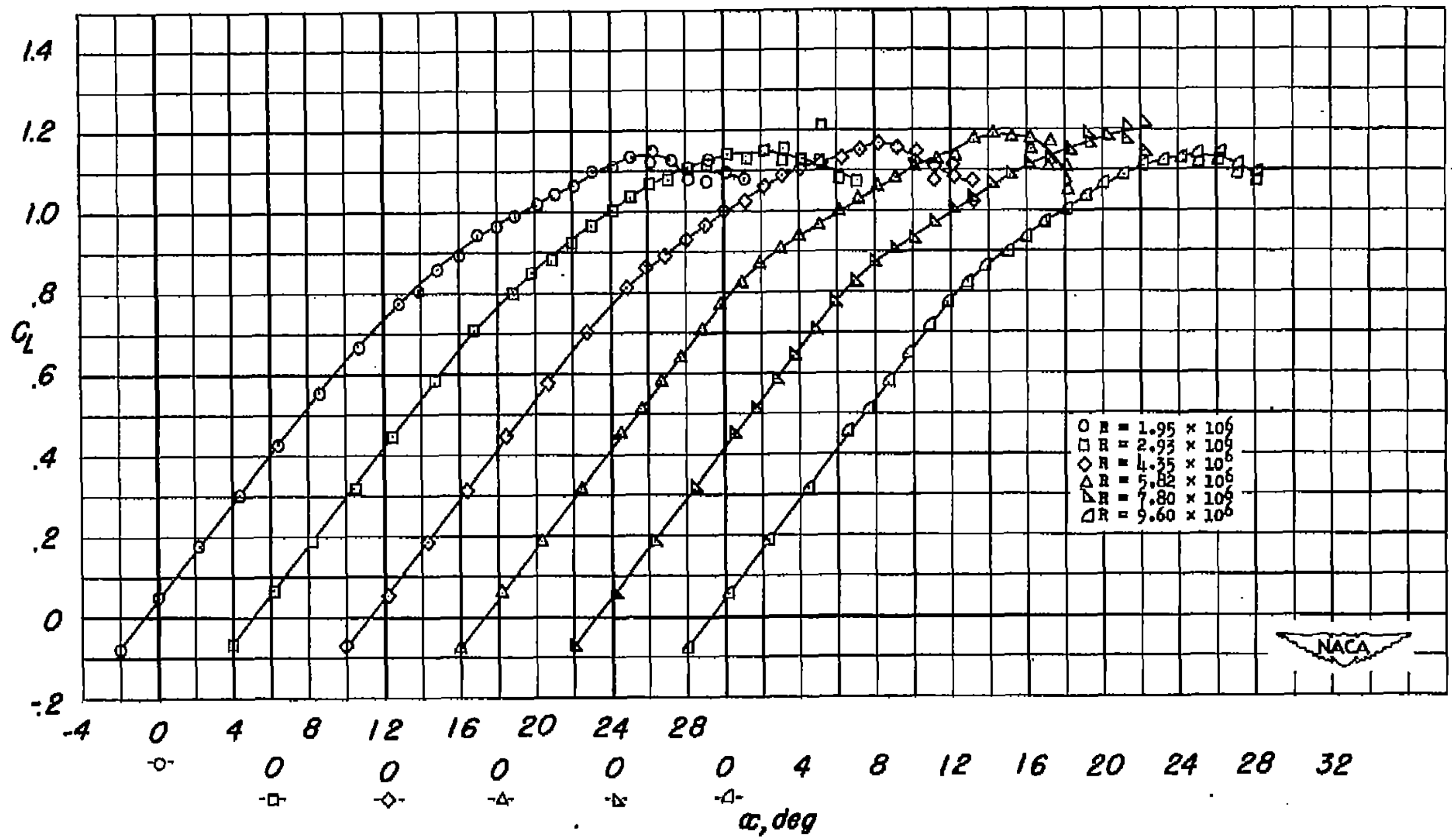
(b) C_L and α plotted against C_m.

Figure 4.- Continued.



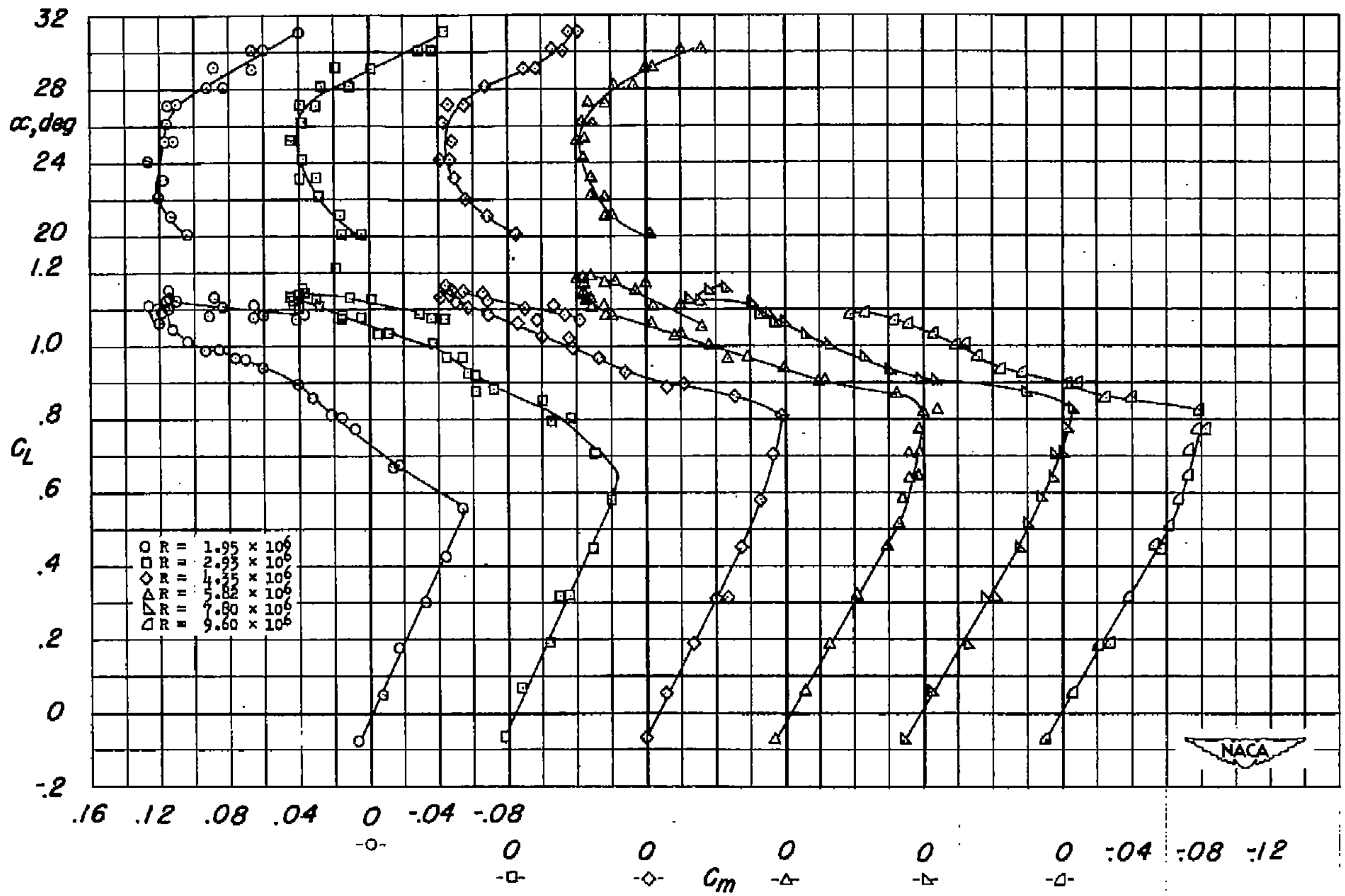
(c) C_L plotted against C_D.

Figure 4.- Concluded.



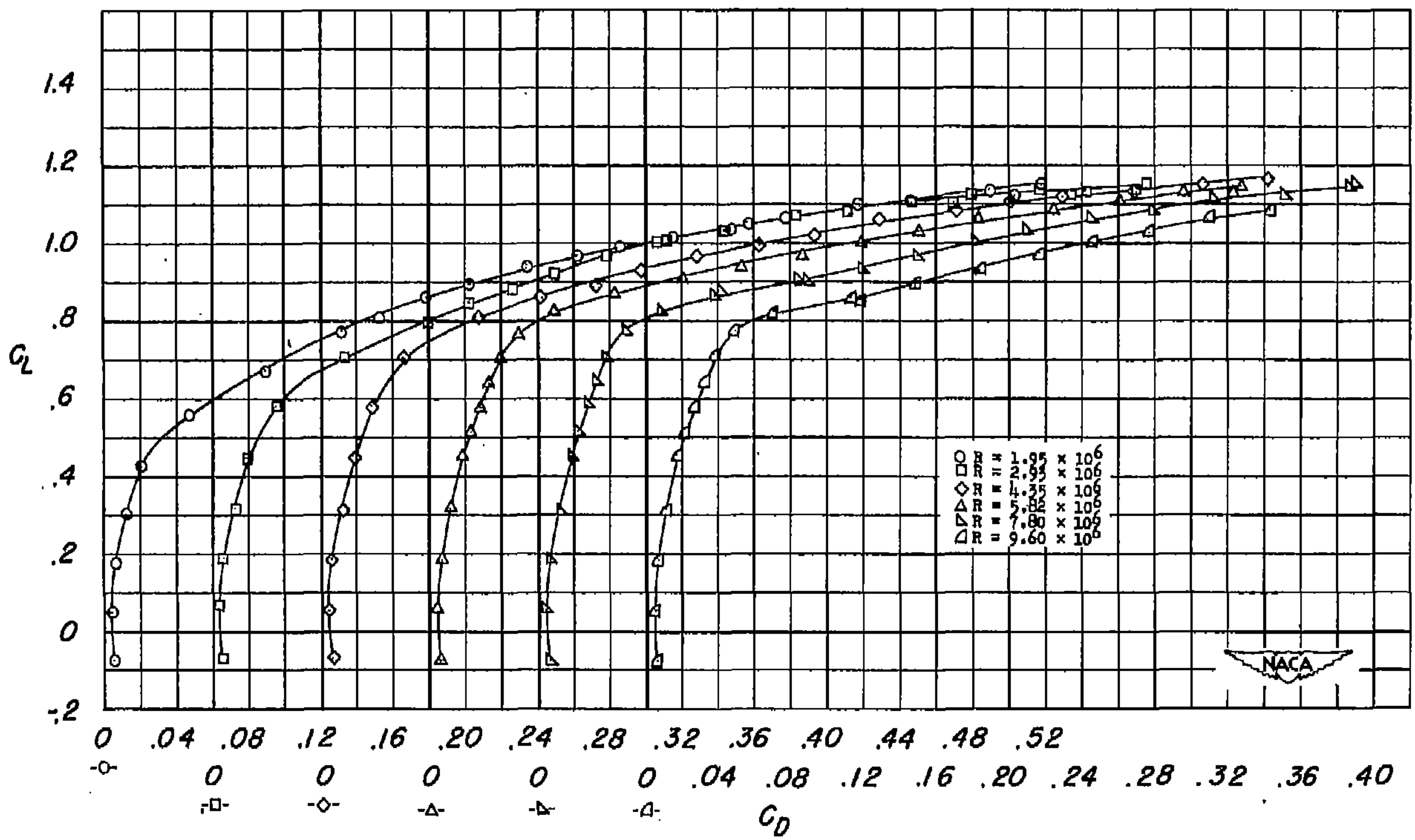
(a) C_L plotted against α.

Figure 5.- Effects of Reynolds number on the aerodynamic characteristics of a 47.7° sweptback wing of aspect ratio 6.0.



(b) C_L and α plotted against C_m.

Figure 5.- Continued.



(c) C_L plotted against C_D.

Figure 5.- Concluded.

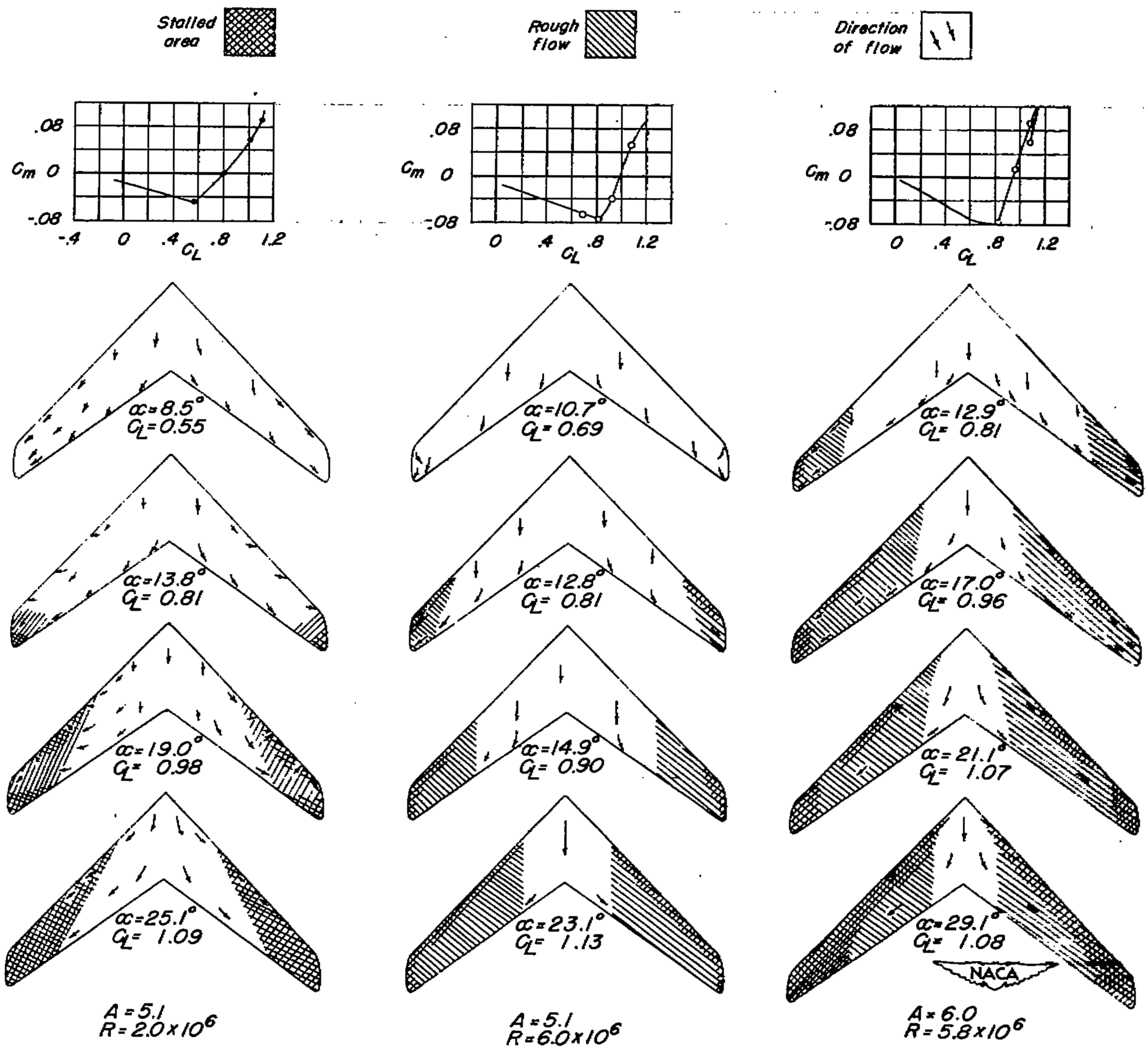


Figure 6.- Stalling characteristics of the 47.7° sweptback wings with aspect ratios of 5.1 and 6.0.

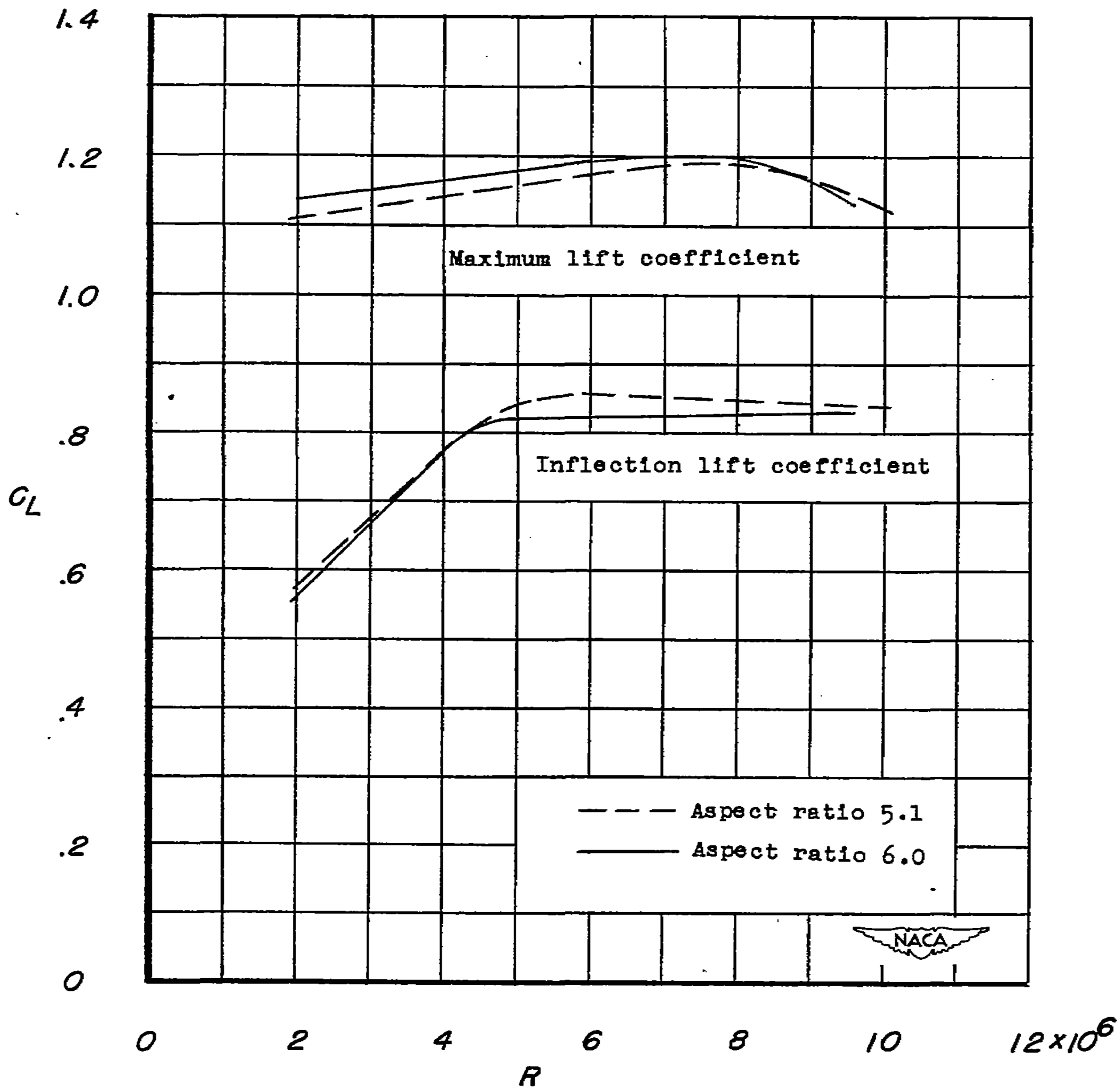


Figure 7.- Variation of the maximum lift coefficient and the inflection lift coefficient with Reynolds number for two 47.7° sweptback wings of aspect ratios 5.1 and 6.0.

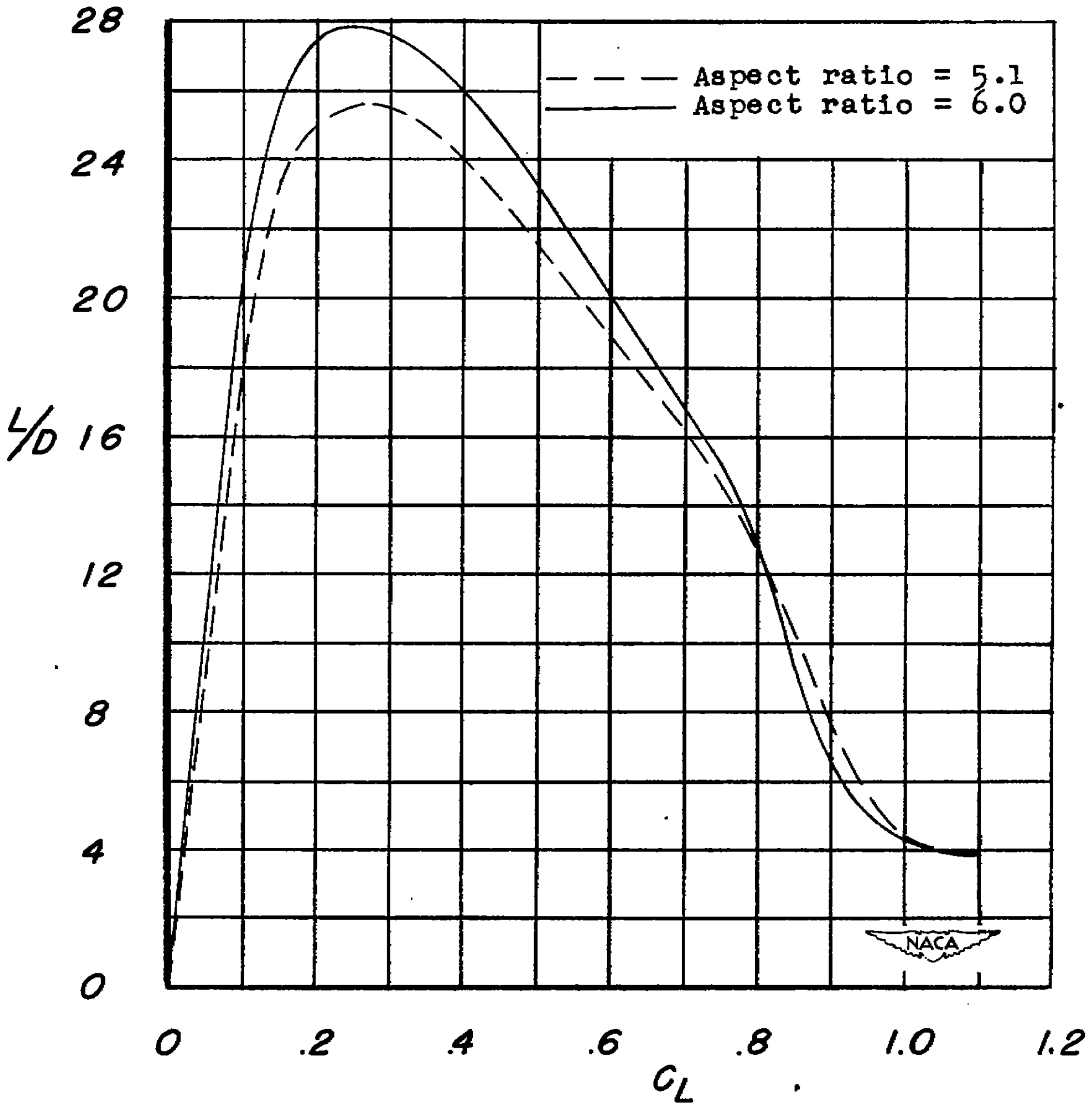
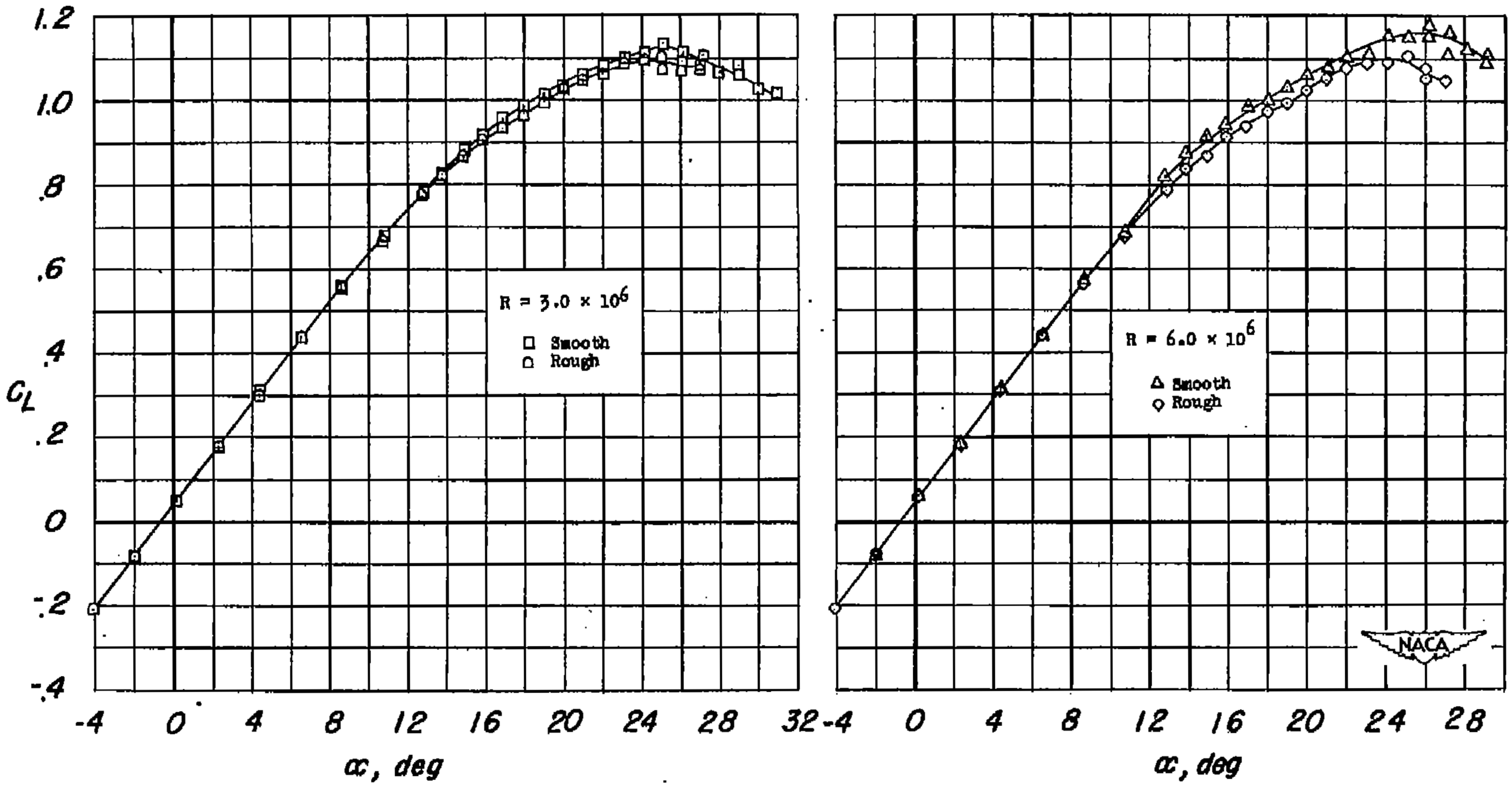
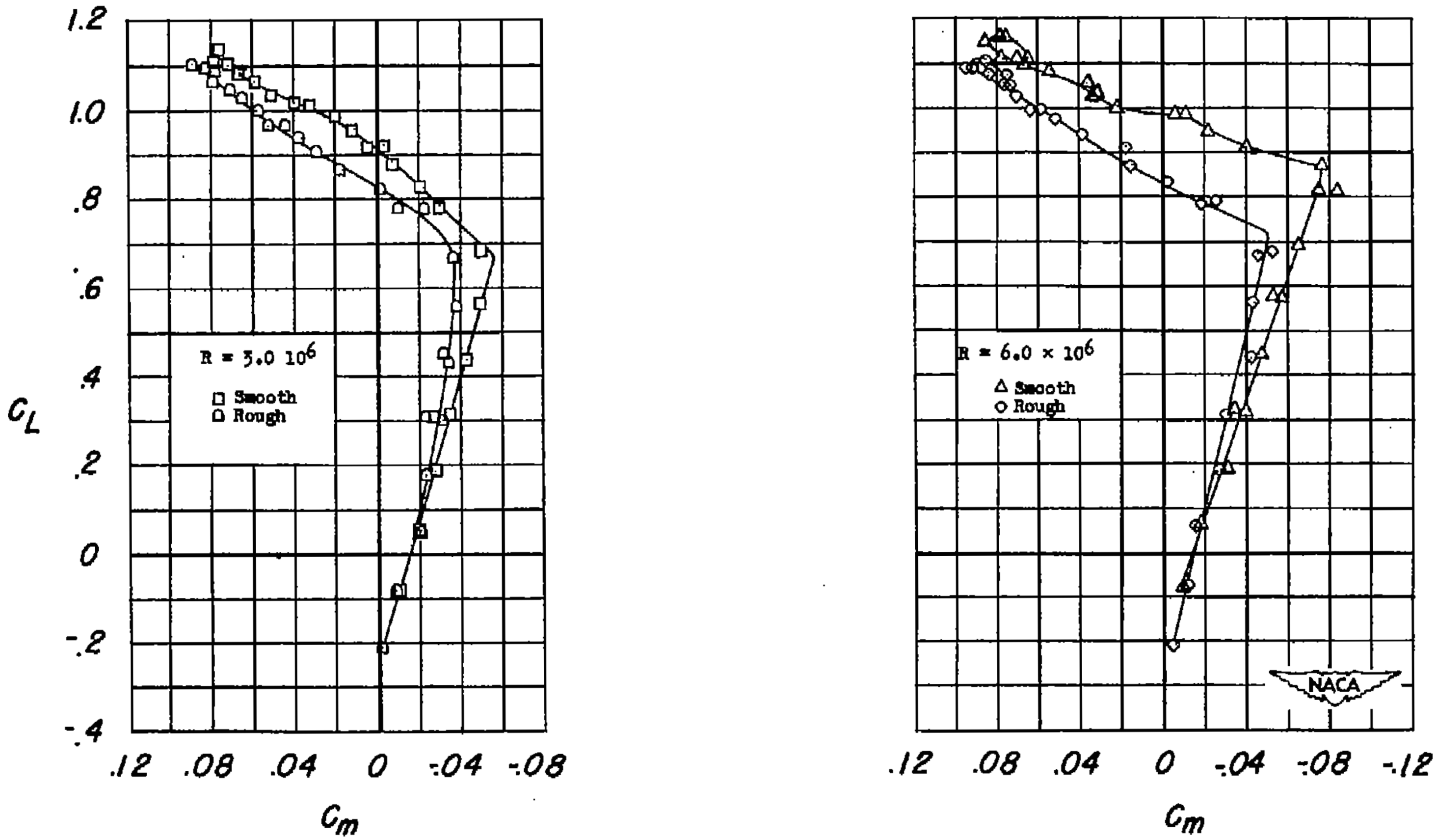


Figure 8.- Lift-drag ratios of two 47.7° sweptback wings of aspect ratios 5.1 and 6.0 at Reynolds numbers of 6,000,000 and 5,820,000, respectively.



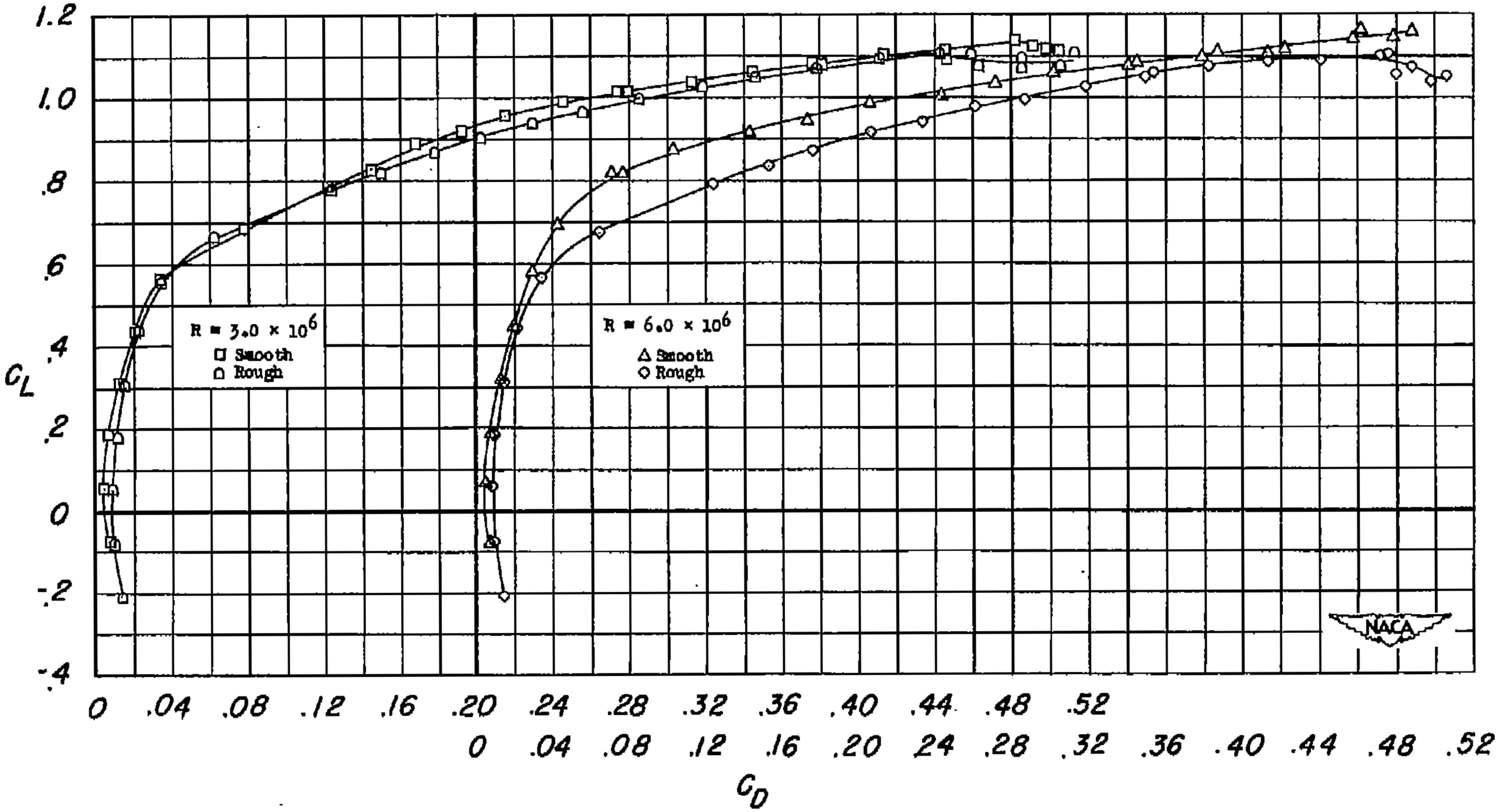
(a) C_L plotted against α.

Figure 9.- Effects of leading-edge roughness on the aerodynamic characteristics of a 47.7° sweptback wing of aspect ratio 5.1.



(b) C_L plotted against C_m.

Figure 9.- Continued.



(c) C_L plotted against C_D.

Figure 9.- Concluded.